

radionuclides

The remnants of the Vela-supernova

This nebula, 6,500 light years from Earth, is the remnant of a supernova that exploded about 10,000 years ago. According to current knowledge, only a few nuclides have been produced during the creation of the universe: they are continuously produced in stars and supernova explosions (nucleosynthesis). Primordial nuclides are those radionuclides, which, because of their long half-lives, are still present and detectable on Earth today (e.g. the human body always contains potassium-40).

Photo: © Anglo-Australian Observatory, photo from UK Schmidt, plates by David Malin

The treasure island of the universe

The Karlsruhe Nuclide Chart - an interdisciplinary tool

Dr. Joseph Magill¹, Gerda Pfennig², Raymond Dreher¹, Dr. Zsolt Solti²

¹ Nucleonica GmbH, Eggenstein-Leopoldshafen, Germany

² Institute for Transuranium Elements (ITU), Karlsruhe, Germany

How old is the mummy of Ötzi the Iceman, how can a brain tumour can be successfully fought, what amounts of radiation exposure predominates in the Fukushima area and how long will it last? Reliable nuclear data is required to answer these and similar questions. When searching for this data, one will quickly encounter the Karlsruhe Nuclide Chart, which has been providing the appropriate information for more than 50 years.

Elements – Isotopes – Nuclides

We all remember the periodic table of elements chart, which probably is still hanging on the walls of the chemistry and physics laboratories of our schools. This periodic table, however, represents only a fraction of all the information on the elements that is available today. For example, the periodic table doesn't provide any information regarding the radioactive properties of the elements and the structures of their nuclei.

Element nuclei are made up of protons and neutrons, whereby the number of neutrons may vary. The atoms with their different number of neutrons are called element isotopes. An isotope is characterised by the name of the element, for instance iodine (chemical symbol I), and the total number of protons and neutrons in its nucleus. The stable isotope of iodine has 53 protons and 74 neutrons and is therefore called iodine-127 or I-127. All other iodine isotopes however are unstable, i.e. radioactive. They decay by emitting high-energy alpha, beta and gamma radiation. During the last weeks for instance, there was frequent discussion about iodine-131 in connection with the Fukushima reactor explosions. This radioactive isotope is produced during the fission of uranium nuclei in nuclear power plants. Iodine-131 has 53 protons and 78 neutrons. The number of its atoms is halved within 8 days, i.e. the half-life of iodine-131 is 8 days.

Representation of Nuclides

If one refers to isotopes of a single element, the respective term for atoms with different numbers of protons and neutrons is nuclides. A total of more than 3000 nuclides are known to date. A nuclide chart shows all of these nuclides in a clear graphical representation, whereby every nuclide is shown in a separate box with the element name, mass number and its main properties in a two-dimensional coordinate system for proton and neutron numbers. In its overall appearance the formation looks like the image of an island (refer to Figure 1).

The periodic element table and its arrangement of the outer electrons in their shells permits the assignment of elements into certain groups and therefore a prediction of chemical properties. However,

the properties of the nuclides are determined by the structure of the atomic nuclei, so the nuclear chart can also differentiate between the isotopes of an element.

The Karlsruhe Nuclide Chart

The best-known nuclide chart reflecting the current state of science stems from Karlsruhe. The Karlsruhe Nuclide Chart shows detailed and structured data of the half-lives and decay modes of the radionuclides and the energy they emit. Each nuclide has an allocated box with the relevant information (Fig. 2). The different colours of the box represent the different types of decay. The colour yellow indicates alpha decay; beta and beta+ decay are indicated by the colours blue and red. Green marking on the other hand represents spontaneous fission (sf). Black boxes denote stable nuclides.

A variety of scientific disciplines benefit from the Karlsruhe Nuclide Chart. In order to date objects by C14-dating, archaeologists need the most accurate half-lives specified in the chart. In nuclear medicine, radionuclides are used to fight cancer cells. In this aspect the physicians need information regarding the energy of alpha and beta particles and gamma photons that are emitted during radioactive decay.

Physicists need similar information to calculate the fission heat of the reactors in Fukushima. The Karlsruhe Nuclide Chart is an indispensable interdisciplinary tool, as it allows a quick overview

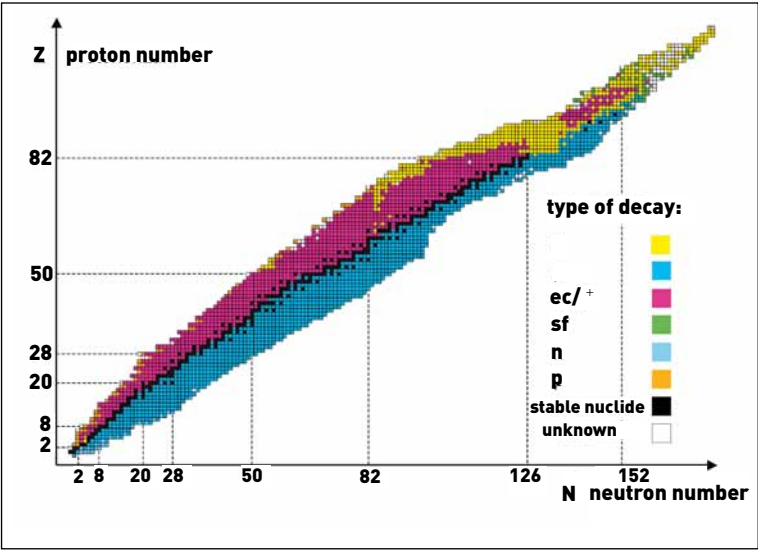


Fig. 1 Typical arrangement of a nuclide chart (example: Karlsruhe Nuclide Chart)

radionuclides



of the properties of the radionuclides and their fission products produced by nuclear reactions or nuclear fission. The fact that the isobars (nuclides with the same mass number) of mass 5 (Fig. 2) are extremely unstable, explains to cosmologists why the first minutes of the Big Bang produced only a few heavier nuclides; the isobar 5 is a bottle neck of the neutron capture reactions.

The history of the Karlsruhe Nuclide Chart

The impetus for the development of the Karlsruhe Nuclide Chart came about in 1956 from a course on radiochemical isotopes by Professor Walter Seelmann-Eggebert, Professor of Radiochemistry at the Technische Hochschule [Technicon Karlsruhe. Seelmann-Eggebert, who at that time was also head of the radiochemical institute of the nuclear reactor construction and operating company – today's Karlsruhe Institute of Technology (KIT) – published in 1958, together with Gerda Pfennig, the first printed Karlsruhe nuclide chart (Fig. 3). Gerda Pfennig, who at that stage was working at the Institute for Radiochemistry, has continued working on the development of the chart, from the first edition in 1958 to today.

During the following decades the Karlsruhe Nuclide Chart, which attracted great interest right from the start, has been reedited various times and has been revised by further authors (H. Münzel and H. Klewe-Nebenius). The current 7th edition dates from the year 2006 (authors: J. Magill, G. Pfennig, J. Galy). The European Commission with their Institute for Transuranium Elements in Karlsruhe played a leading role in this regard.

The 3rd edition dated 1968 already contained explanations in four languages (German, English, French, Spanish); 2006 saw the addition of Russian and Chinese. The first nuclide chart dated 1958 contained 267 stable, over 1030 unstable nuclides and 220 isomers of the 102 chemical elements known then. In comparison, the latest edition of 2006 contains data for 2962 experimentally observed nuclides and 652 isomers of 118 elements.



Joseph Magill studied physics at the University of Strathclyde in Scotland and was awarded a PhD in 1975 by the University of Glasgow. After graduation, he joined the Institute for Transuranium Elements in Karlsruhe, an institute of the Joint Research Centre of the European Commission. Magill has published several books on nuclear science, more than 150 scientific papers and patents. In March 2011 he founded the NUCLEONICA GmbH as a spin-off of the European Community.



Gerda Pfennig trained as a chemistry assistant at the Fresenius Academy in Wiesbaden. In 1956 she joined the radio-chemistry group of the Kernreaktor Bau- und Betriebsgesellschaft [nuclear reactor construction and operating company]. Since then she has worked continuously on the Karlsruhe nuclide chart in order to keep it constantly up to date.



Raymond Dreher studied physics at the Institut National des Sciences Appliquées de Lyon [Institute of Applied Sciences in Lyon]. He first worked at the University of Karlsruhe, then at a software company. A few years ago, R. Dreher strengthened the Nucleonica Team at the ITU and is now working at the newly founded Nucleonica GmbH.



Zsolt Solti studied mathematics and computer science. He worked as a scientist at medical universities in Hungary and in Germany, where he was awarded his doctorate. For more than 15 years he developed computer programs and methods for diagnostic radiology and nuclear medicine. In 2009 he joined the Institute for Transuranium Elements in Karlsruhe and works on the Karlsruhe Nuclide Chart.

radionuclides

The future of the Karlsruhe Nuclide Chart

2011 saw the start of the spin-off NUCLEONICA GmbH through a licensing agreement with the Joint Research Centre of the European Commission, Institute for Transuranium Elements, one of whose tasks is

to maintain the nuclear science web portal NUCLEONICA and to keep it up to date at the latest scientific level (see box). A further task is to develop and distribute the Karlsruhe nuclide chart.

They are already working intensely on the forthcoming 8th Edition. There is a lot to be done – just last year more than

100 new nuclides were detected worldwide using the latest experimental methods in different laboratories (e.g., Joint Institute for Nuclear Research, Dubna, Russia; GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany, Lawrence Berkeley National Laboratory, Berkeley, California, Nishina Center for Accelerator-Based Science, RIKEN, Wako, Japan – see for example the contribution from IAEA on the initial detection of the chemical element 117: Hofmann, S., 2010, labor&more 3, 42-44).

The Nucleonica team has to collect, analyse and integrate this data into the Karlsruhe Nuclide Chart.

Today, the Karlsruhe nuclide chart is available in the form of a wall chart (0.96 m x 1.36 m) and as a brochure with a fold-out chart (A4 format). This will remain so in the future. In addition, there will be an auditorium chart, for example for the lecture hall. A further innovation is the planned electronic version, which will then be available on the science portal NUCLEONICA. In other words, the Treasure Island of the Universe will keep on growing.

→ joseph.magill@nucleonica.com

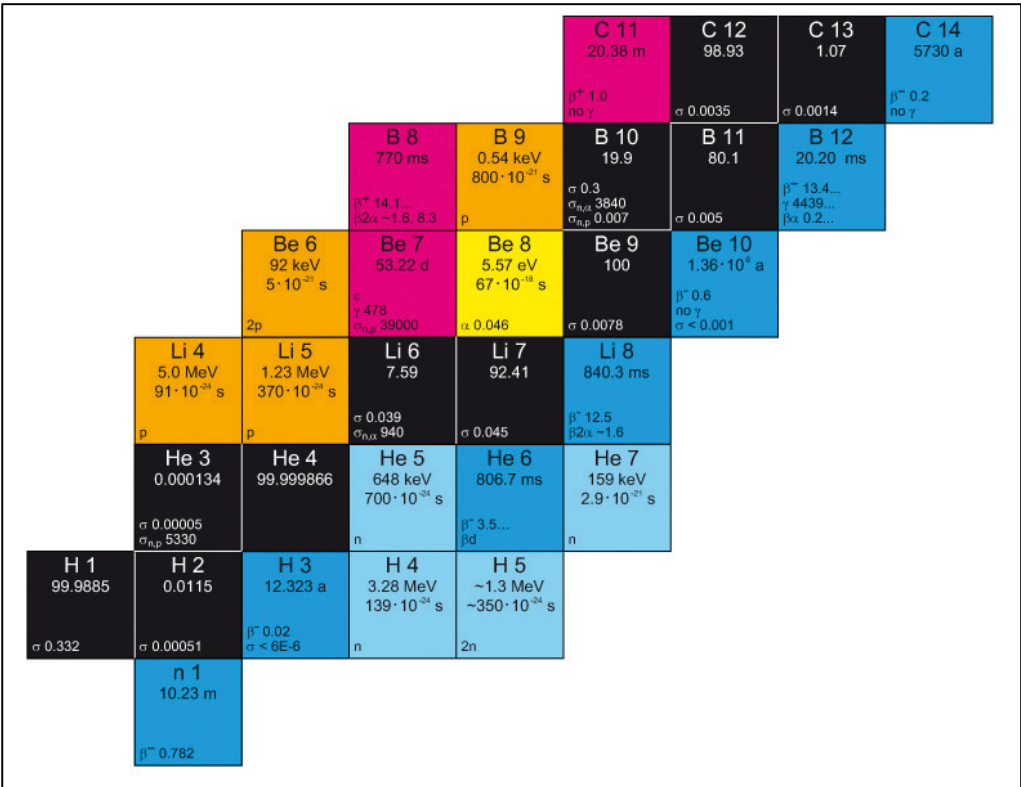


Fig. 2 Box structure of the Karlsruhe Nuclide Chart

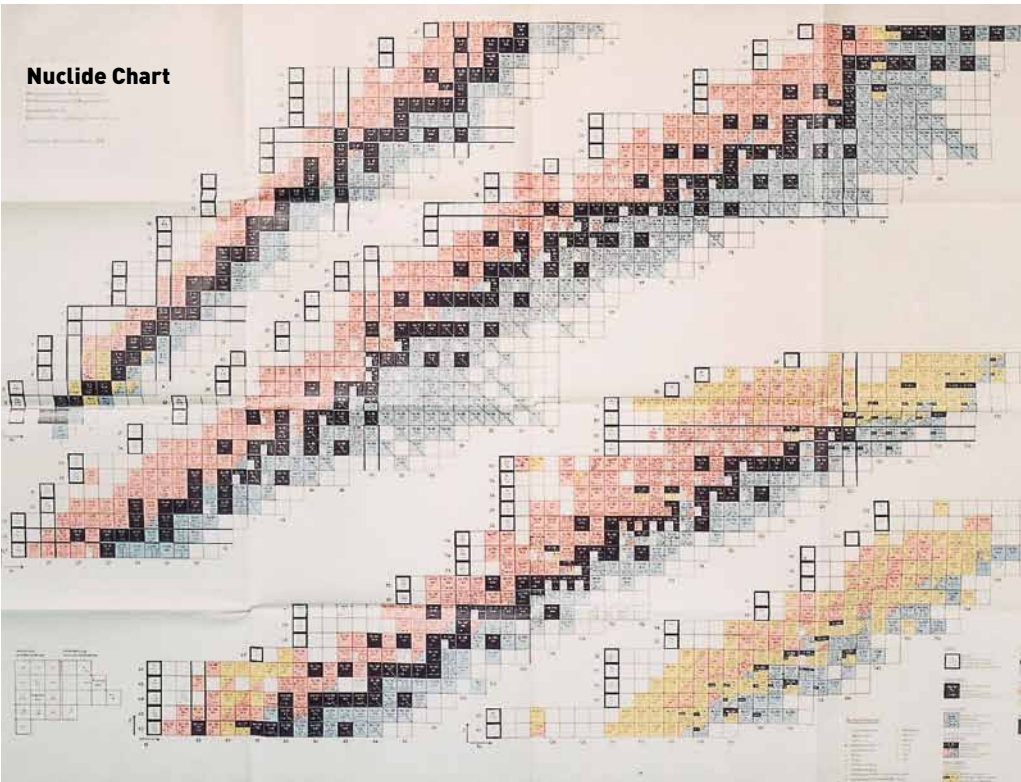


Fig. 3 The first edition of the Karlsruhe Nuclide Chart from 1958

NUCLEONICA – Nuclear Science on the Web

An innovative and versatile tool for scientific work, the web portal NUCLEONICA, was developed at the Karlsruhe Institute for Transuranium Elements during the last few years. This provides scientific and industrial specialists access to all the relevant information and data using the most advanced integrated web applications (cloud computing). Interactive online nuclide charts, application modules for the calculation of decay, dosimetry and shielding are just a few examples of the diverse range of services. Current news and the latest findings from nuclear research are available to the user. Training courses for interested users for the effective use of NUCLEONICA are also organised. The physicist Dr. Joseph Magill, the founder of NUCLEONICA, also offers scientific consulting and contract research. A particular concern for him is the preservation of nuclear knowledge for the next generation of scientists.

→ www.nucleonica.com